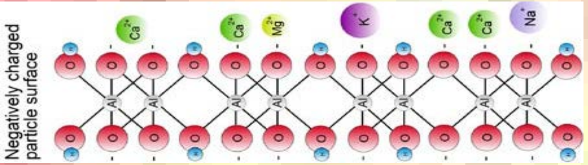
An Uncertainty Analysis for Predicting CEC and salinity Using gamma-ray and EM data

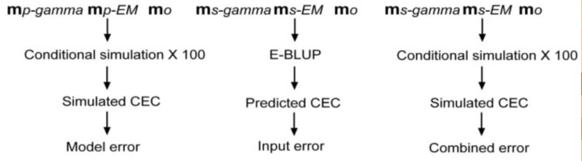
Jingyi Huang, Thomas Bishop,
John Triantafilis

Problem Definition?

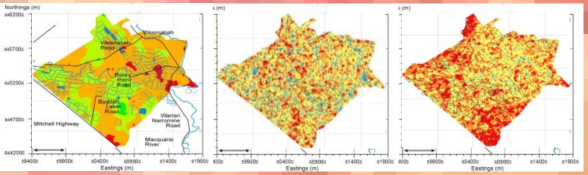


Digital soil mapping; ancillary data

Digital soil mapping; modelling and errors

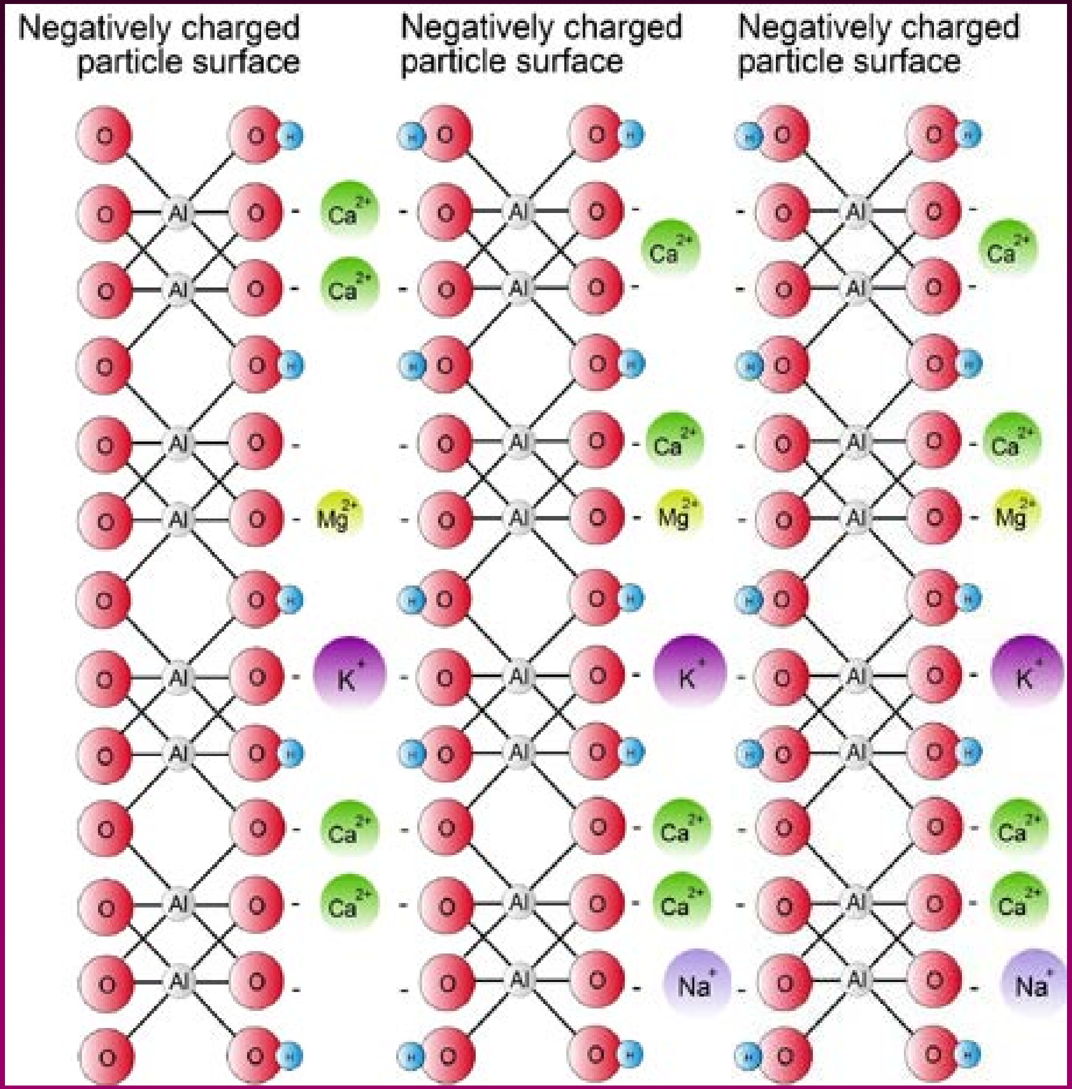


Results, Discussion & Conclusions



Talk Outline

Introduction



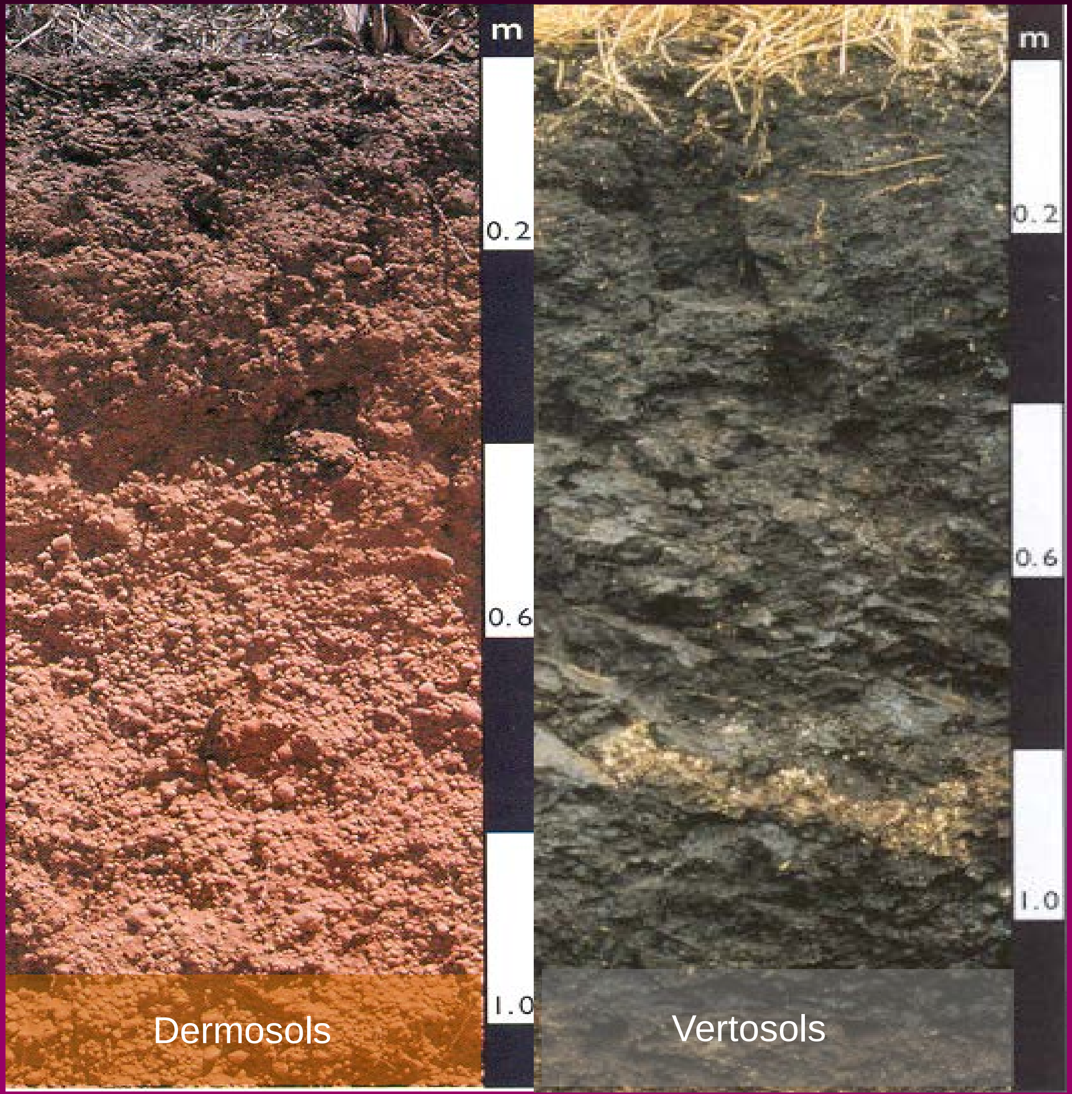
Cation exchange capacity

CEC is the total sum of exchangeable cations that soil can adsorb at a specific pH

It is widely used for agricultural assessment because CEC is a measure of fertility indicator of structural stability/resilience.

The latter is because CEC is capable of enhancing development of shrinkage cracks.

Introduction



CEC and shrink swell

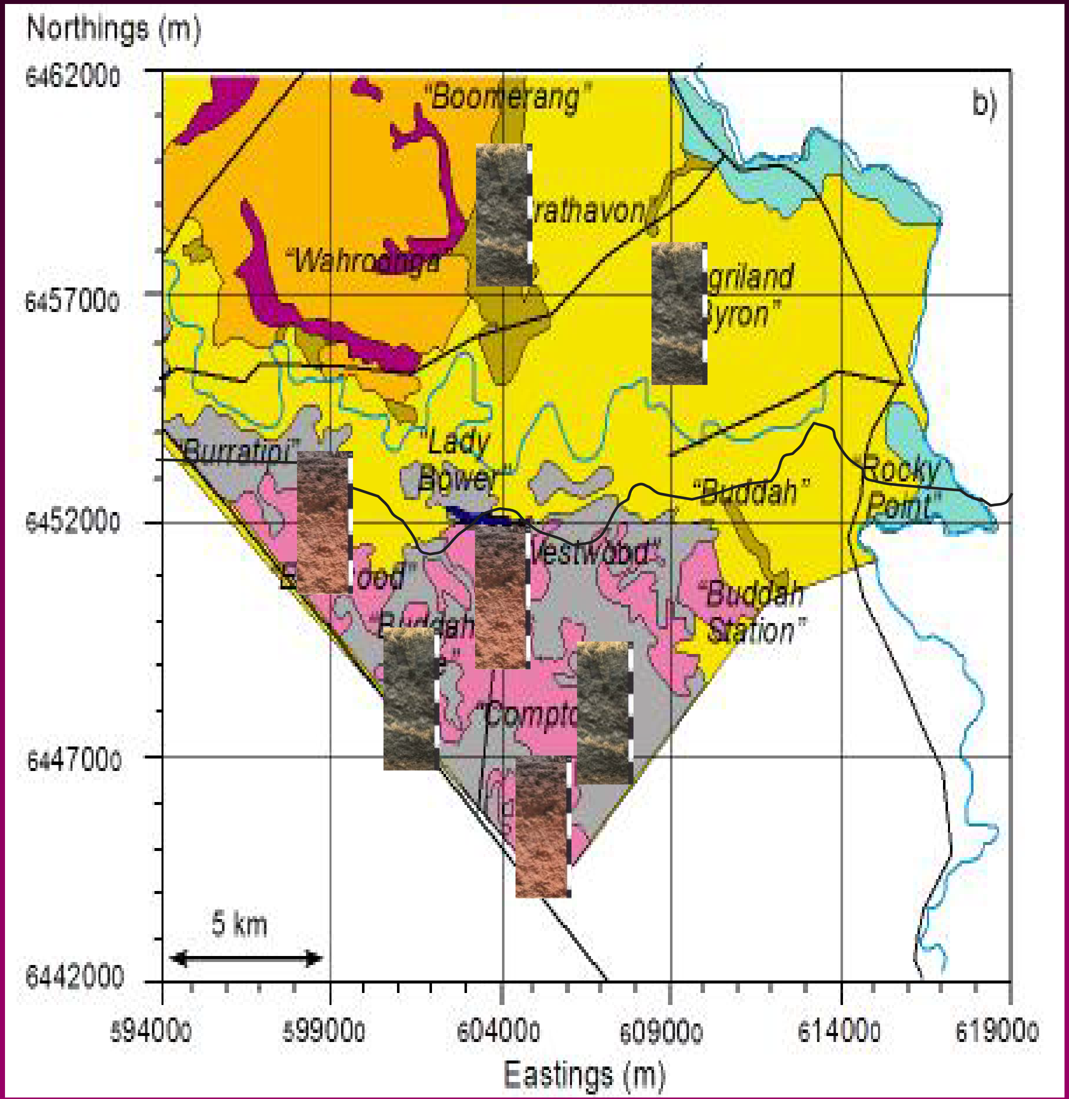
In this regard, critical limits can be used in terms of shrink-swell properties.

Specifically, shrink swell potential

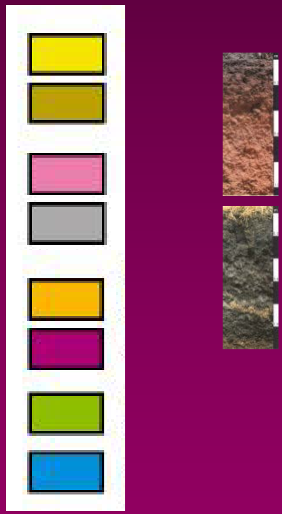
(cmol(+)/kg)	
< 10	Very poor
< 20	Poor
< 30	Moderate
>= 30	Good

CEC is time consuming because analysis requires determination of cations through a leaching process (Holmgren et al., 1977).

Problem definition



Pedoderms (McKenzie, 1992)



Trangie Cowal

Dermosols

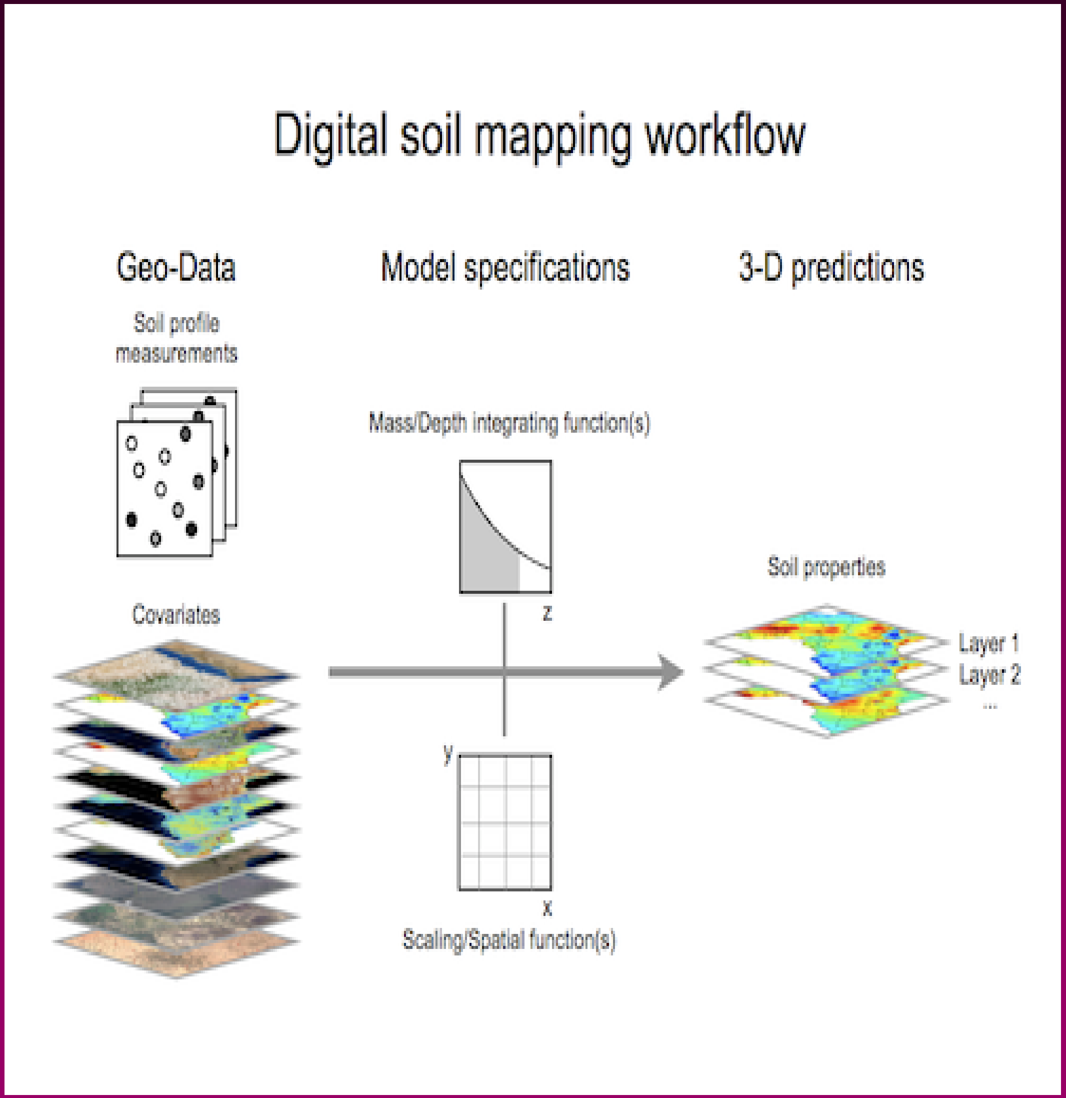
Old Alluvium Meander Plain

Old Alluvium Back Plain

Vertosols

Contemporary Macquarie

Aims and objectives



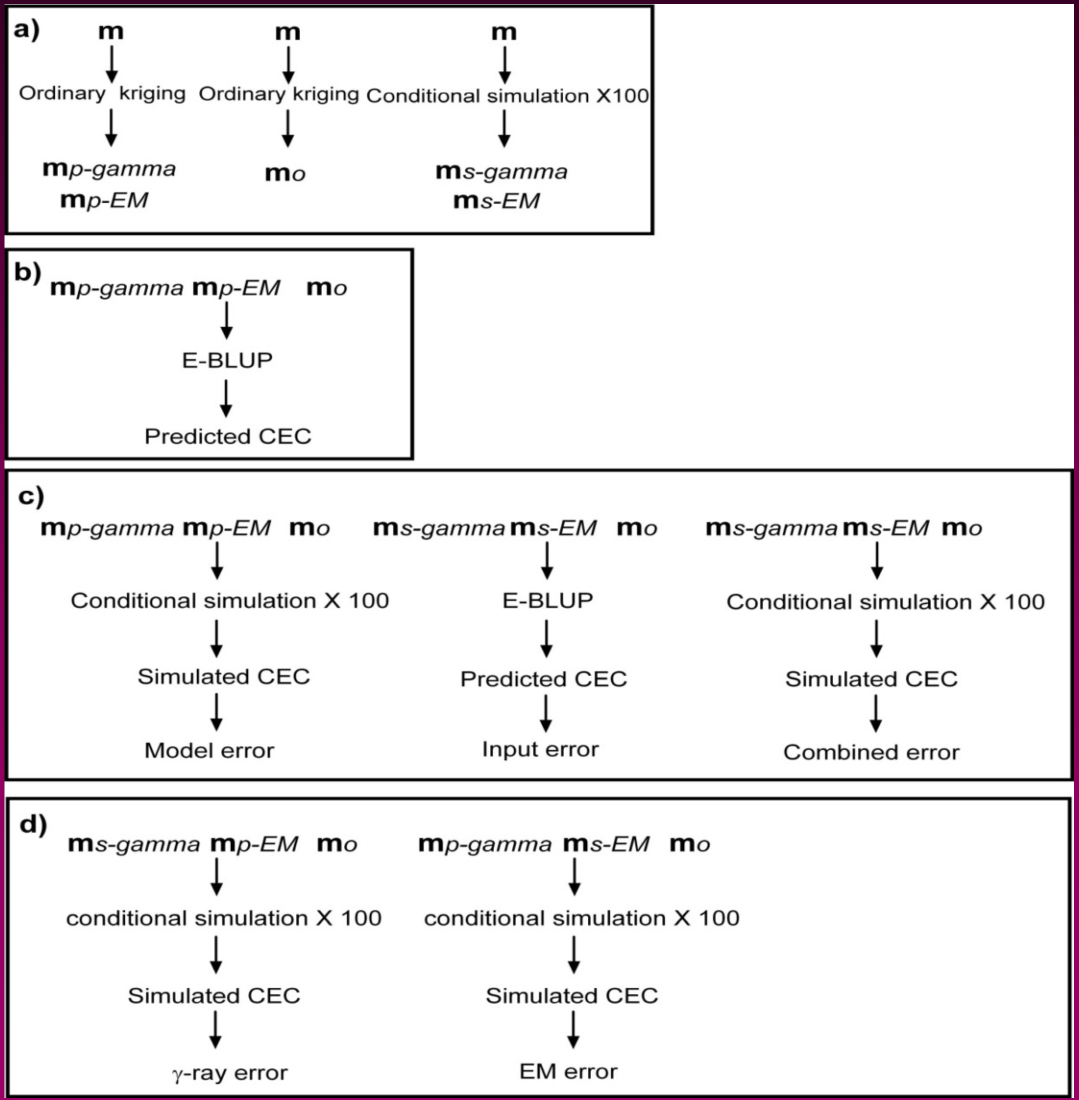
Use of DSM and error budgeting

Develop a DSM of topsoil (0-0.3 m) CEC using
- ancillary data,
- linear mixed model (LMM), and
- restricted maximum likelihood (REML).

Use an error budget procedure to quantify the relative contributions made by
- model,
- input (for both γ-ray and EC_a), and
- individual covariate error (ancillary data) when combining to map topsoil (0-0.3 m) CEC.

To understand distribution of different sources of errors

Materials and Methods: Modelling



Use of DSM and error budgeting

We use

i) empirical best linear unbiased prediction (E-BLUP),

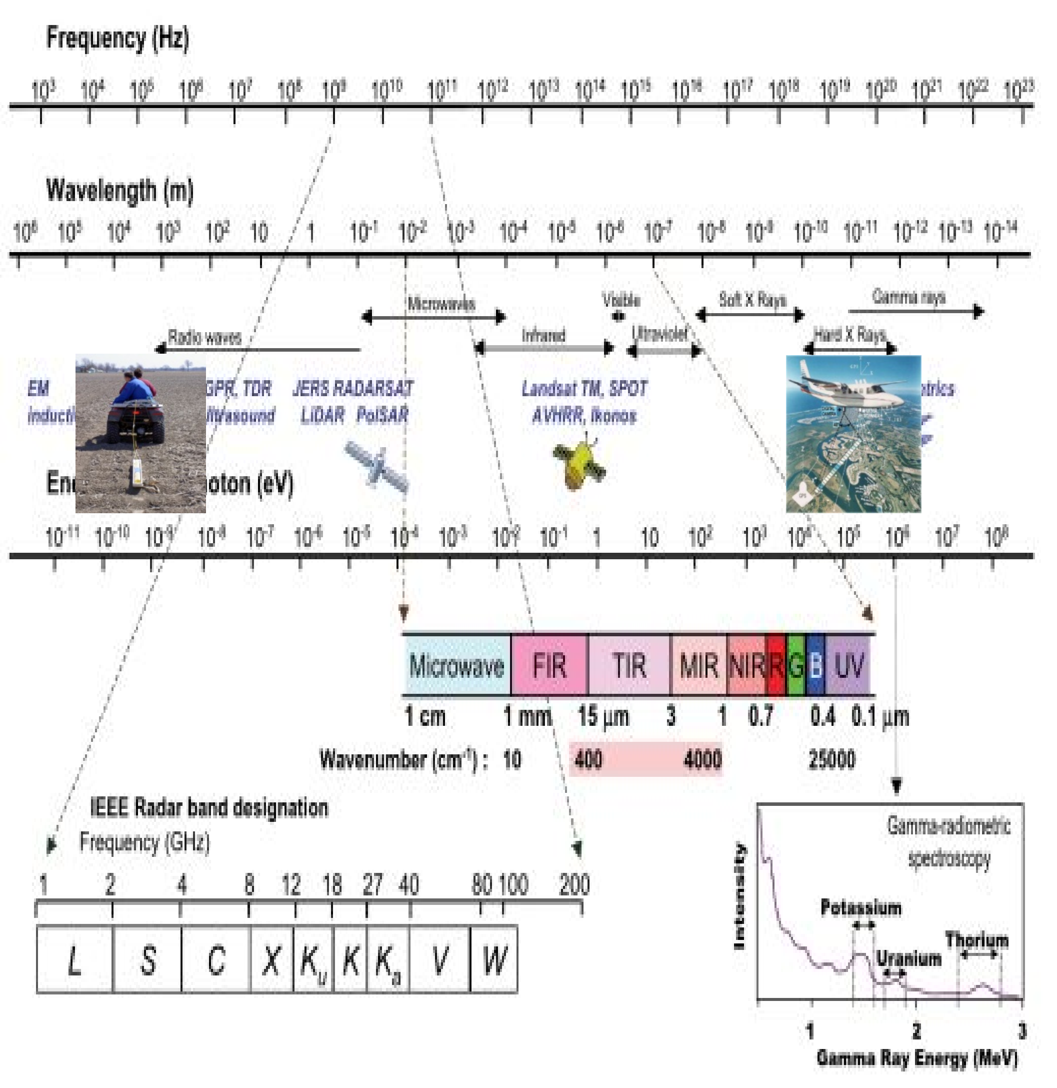
ii) conditional simulation to produce numerous realizations of the data and their underlying errors, with

iii) Linear mixed models (LMM)

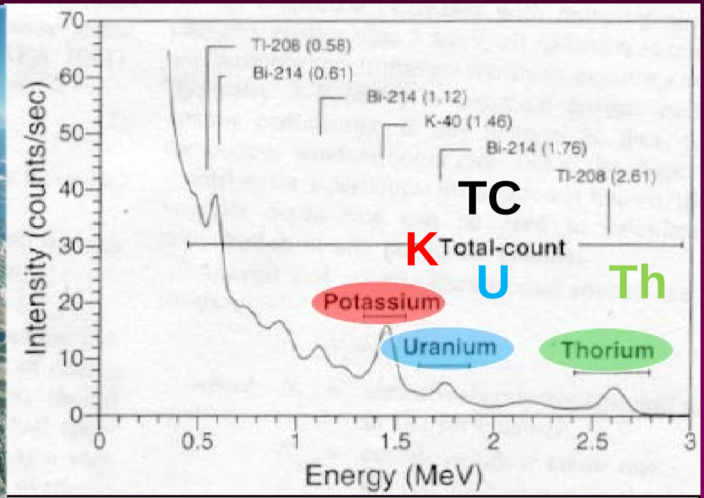
$$\mathbf{y} = \mathbf{X}\boldsymbol{\tau} + \mathbf{Z}\mathbf{u} + \boldsymbol{\varepsilon}$$

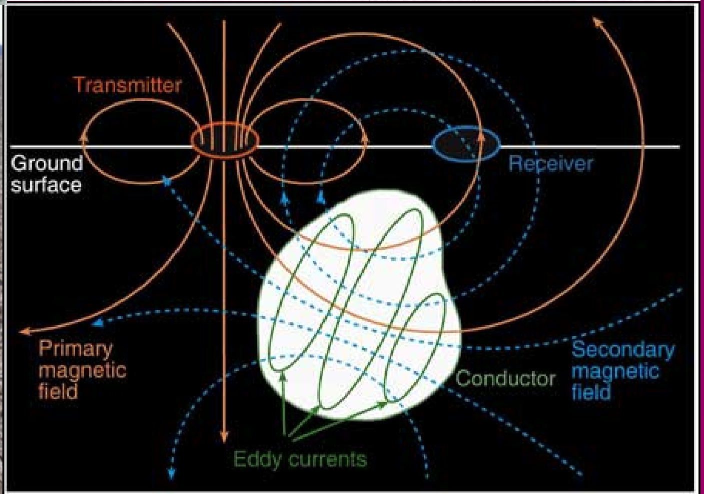
estimated by residual maximum likelihood (REML) to create the prediction models.

Materials and Methods

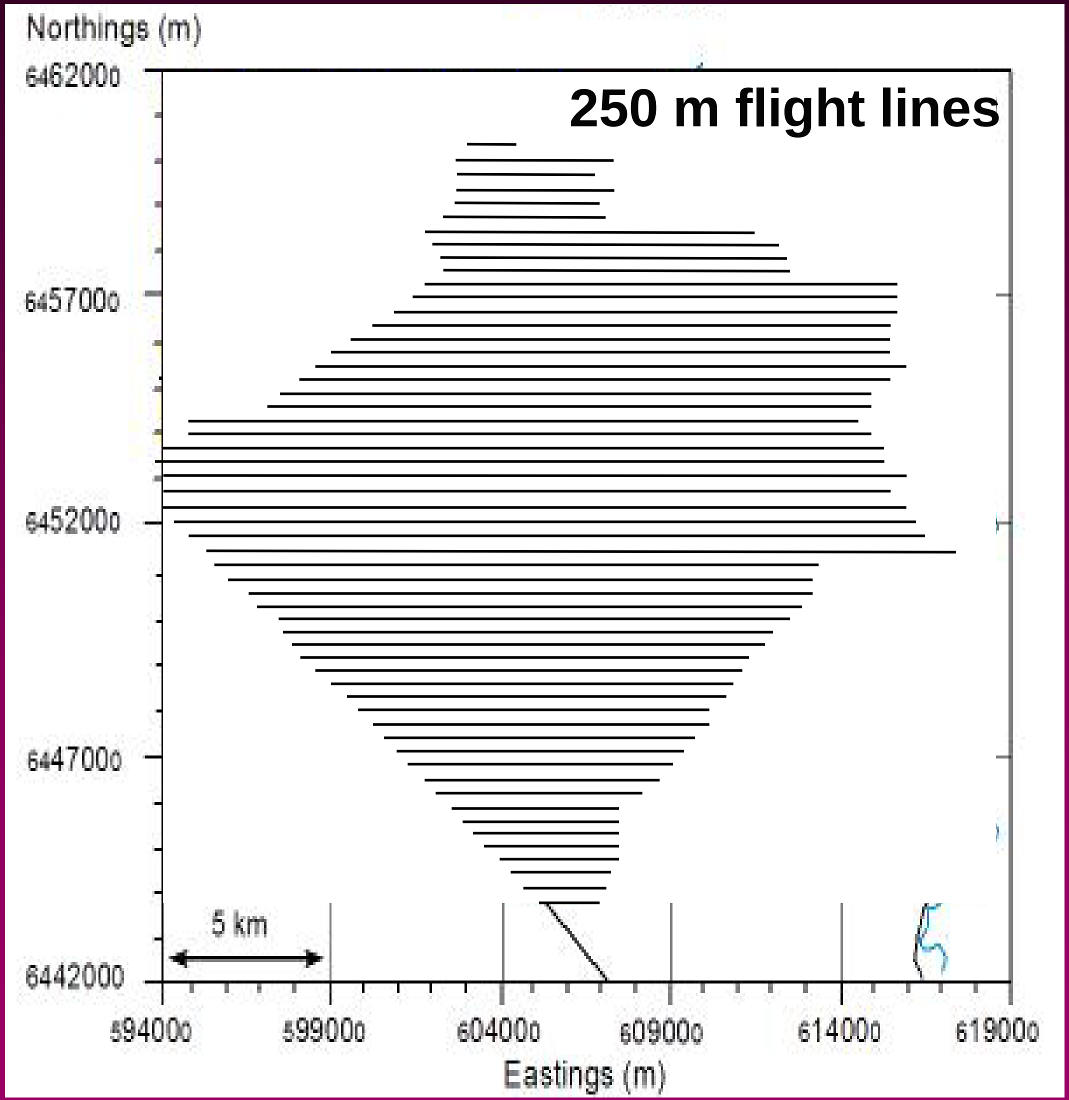


What covariates are commonly used?





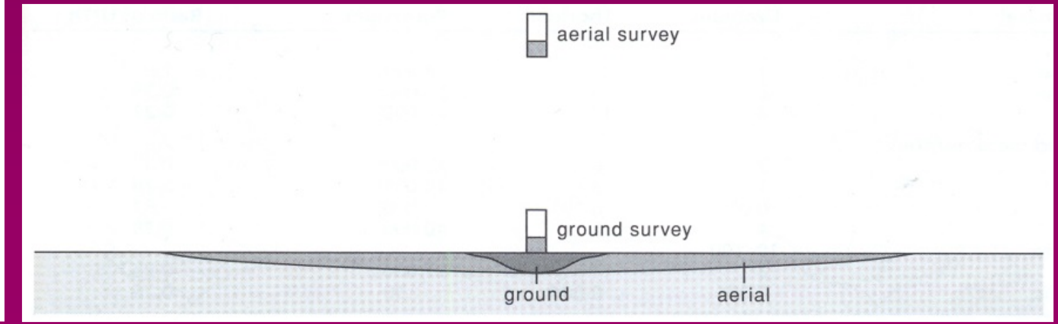
Materials and Methods: Ancillary data



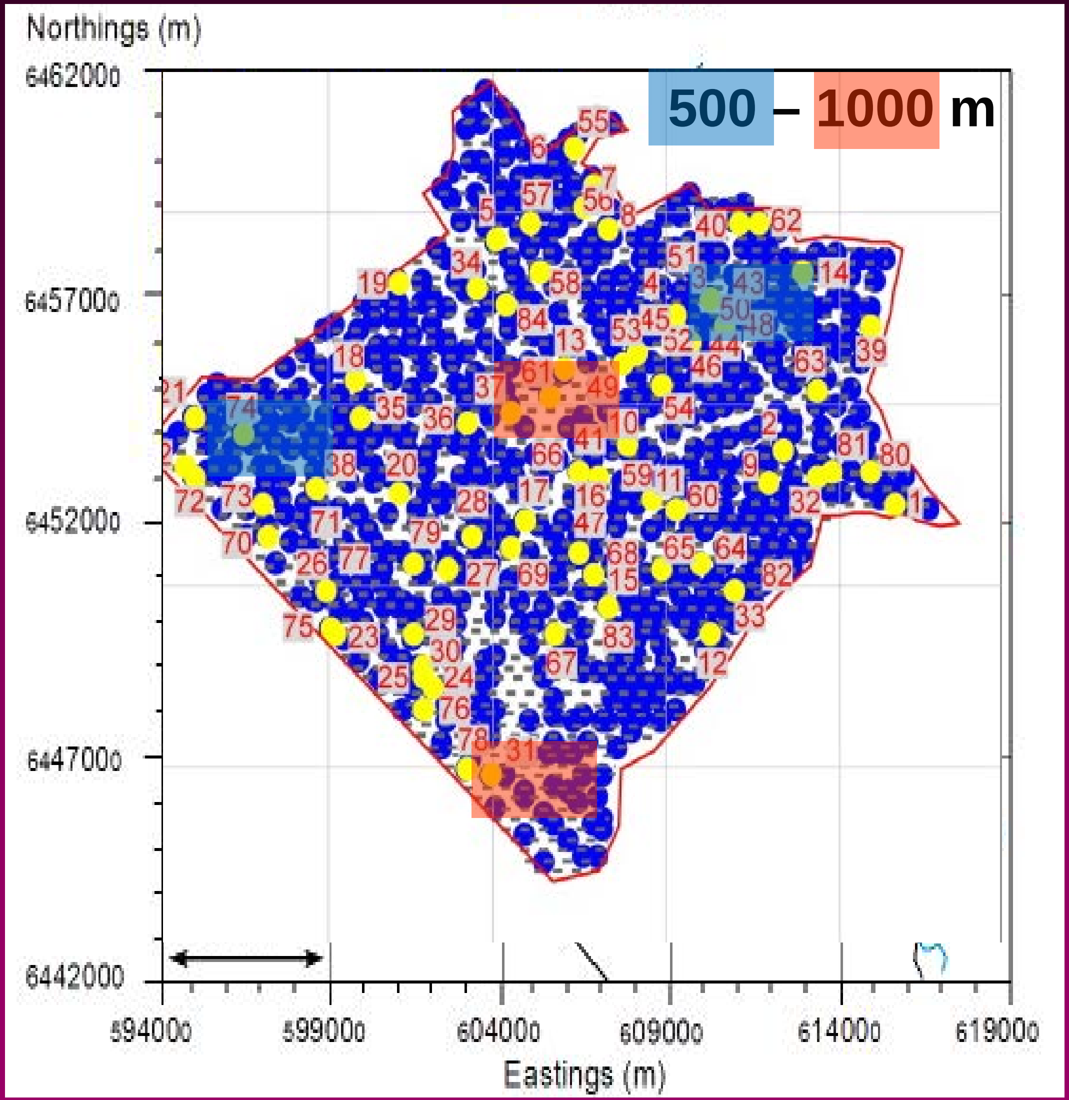
Airborne gamma-ray spectrometry

0

0.4 **K,**
U,
Th, and
TC



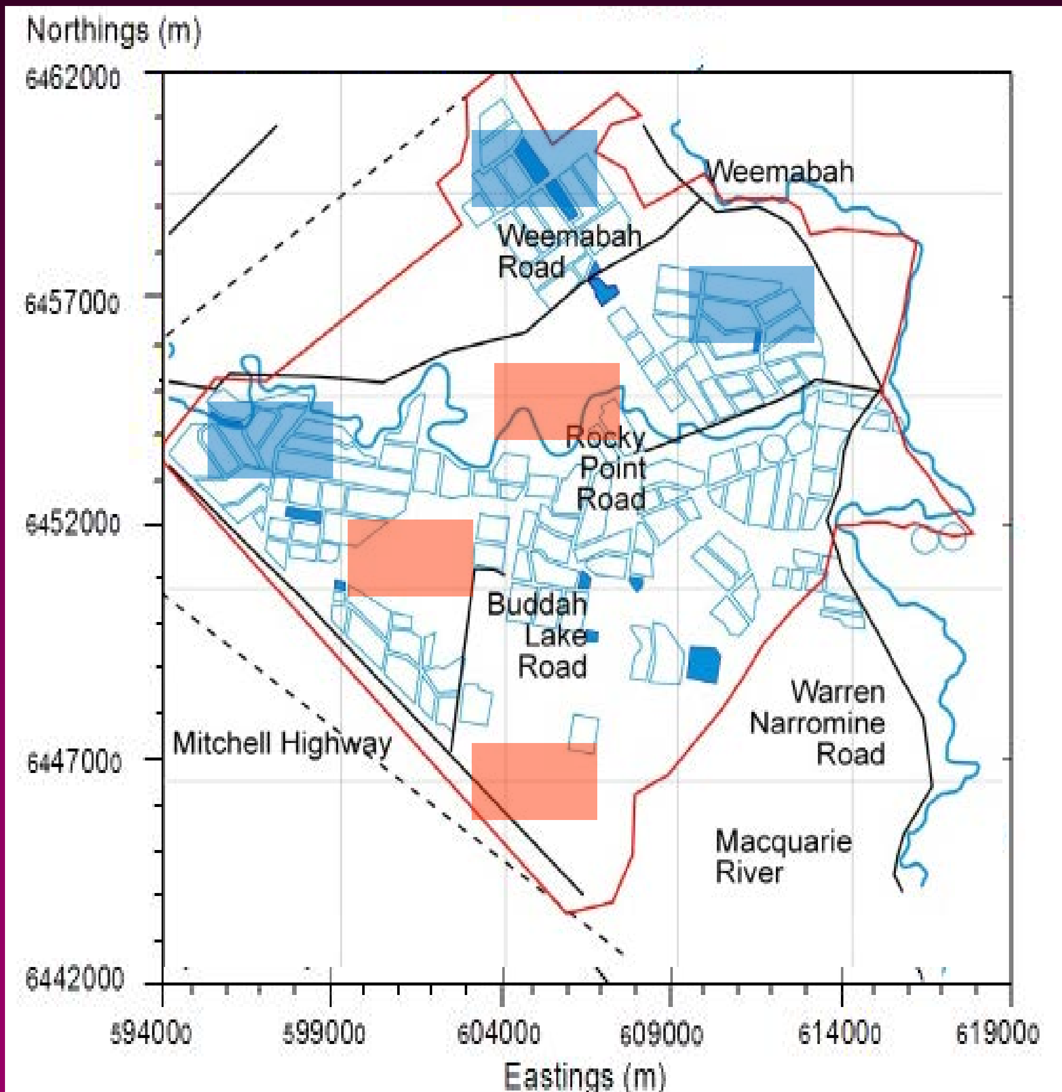
Materials and Methods: Ancillary data



Proximal EM

0	
0.75	EM38h
1.50	EM38v
7 m	EM34-10
15 m	EM34-20
30 m	EM34-40

Materials and Methods



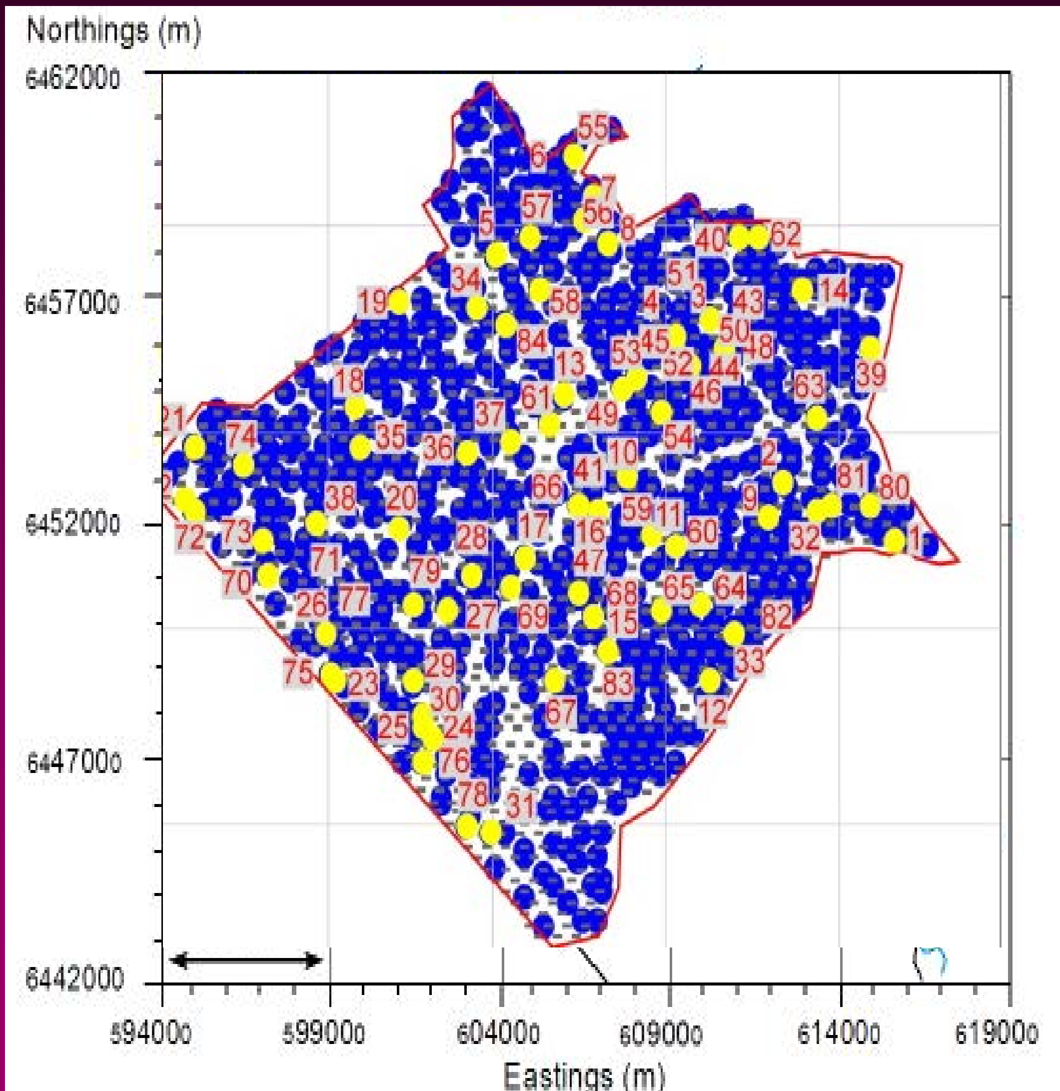
Study area

Trangie
Lower Macquarie valley
Central western New South Wales

Semi-arid
Rainfall - 560 mm/year
Hot summer (>35 ^{o}C)

Land-use includes
grazing for sheep and cattle,
dryland wheat farming, and
irrigated cotton production

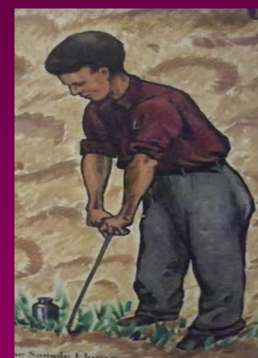
Materials and Methods: Soil data



Soil sampling and laboratory analysis

0 **Topsoil**

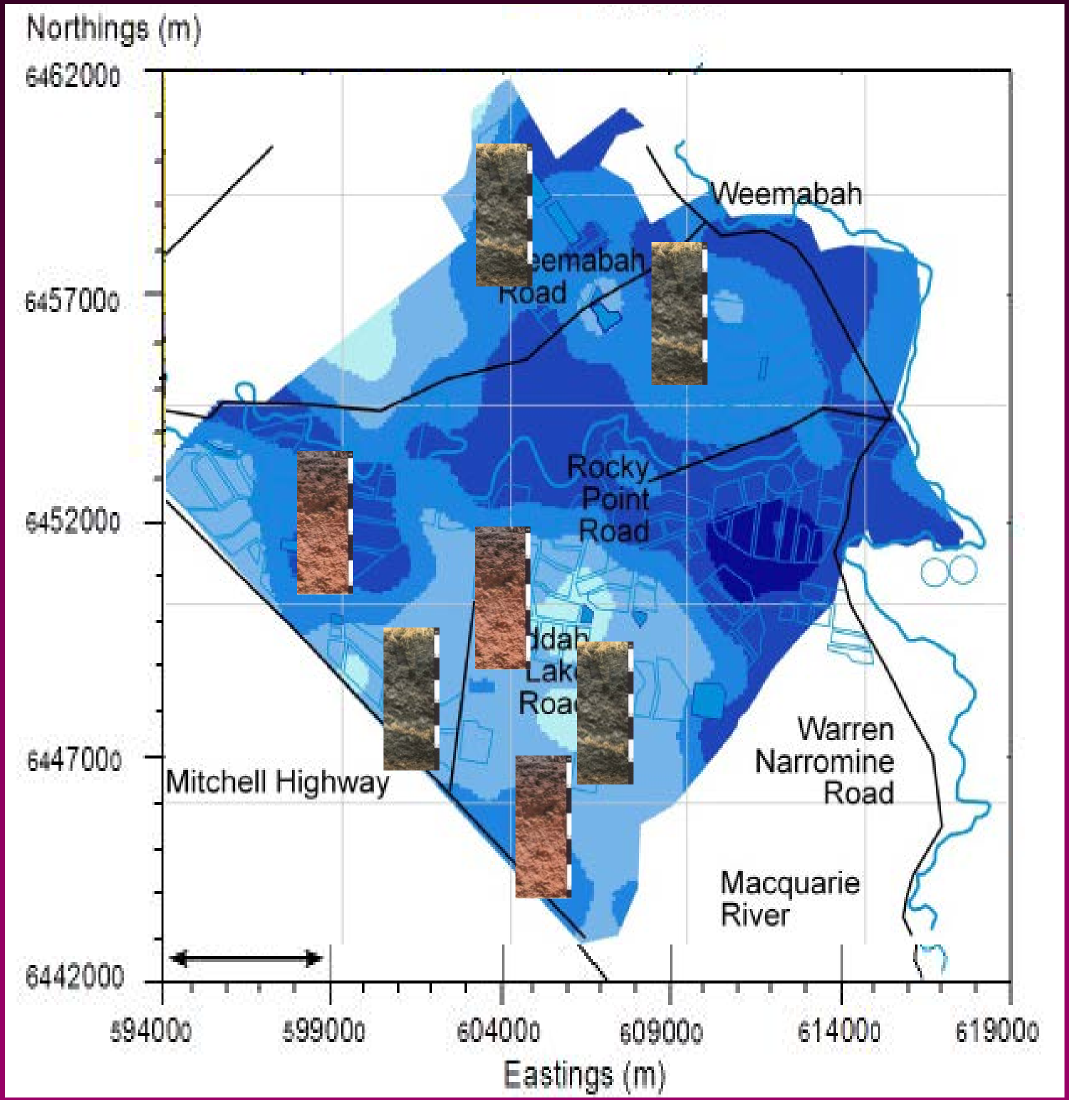
0.30 **CEC**



Soil - sampling based on Response Surface Sampling Design (RSSD) using EM34 (Triantafilis and Lesch, 2005)

CEC - Tucker's (1974) using leaching (Holmgren et al., 1977) because Vertosols alkaline with solid-carbonates (Loveday et al., 1972).

Results and Discussion: Ancillary data



Gamma-ray spectrometry

0 **Topsoil**

0.35 **Uranium**

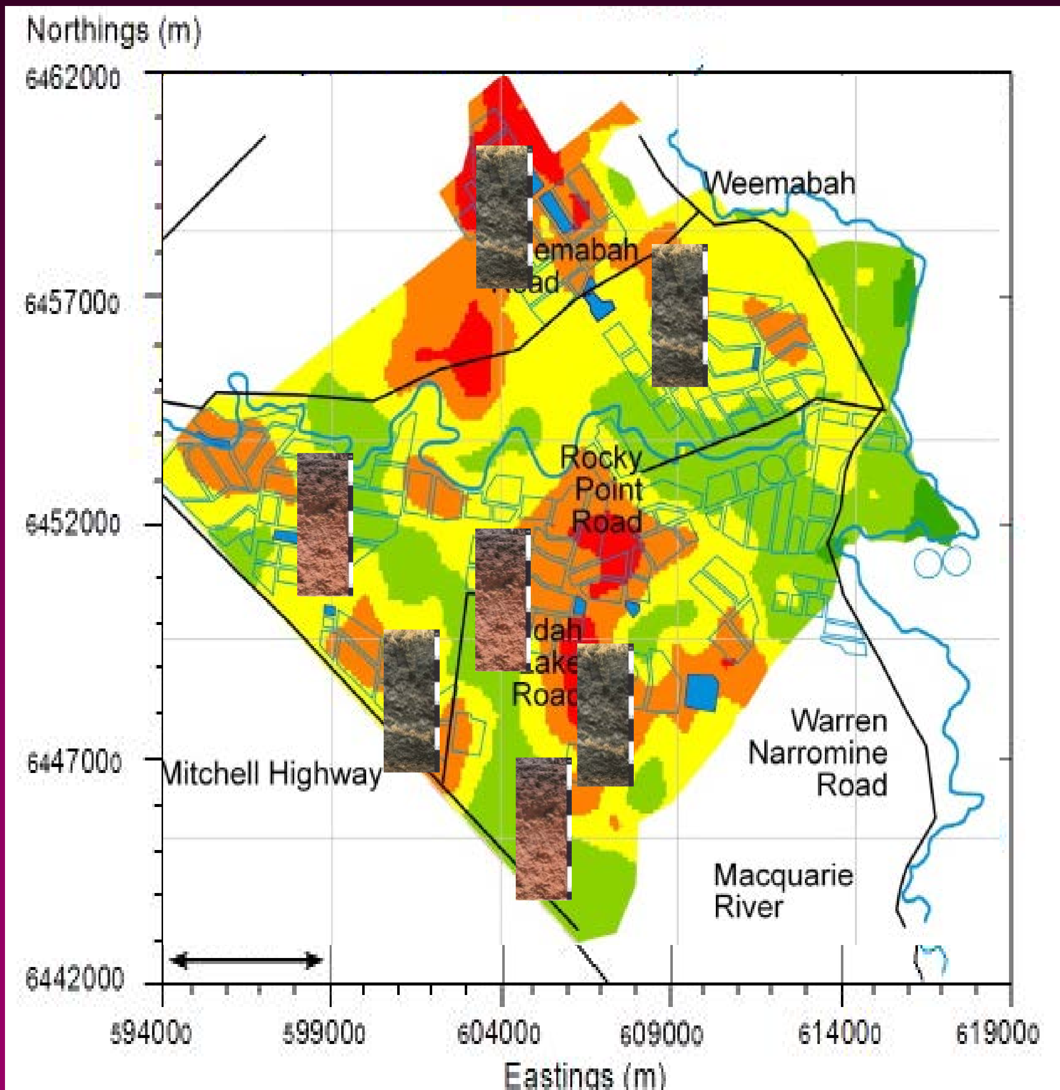
Dermosols

Old Alluvium Meander Plain

Old Alluvium Back Plain

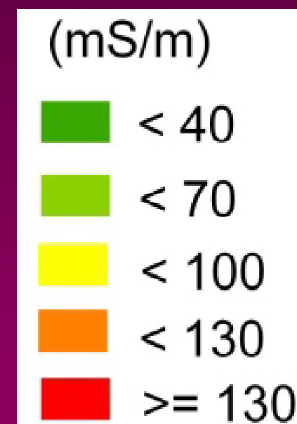
Vertosols

Results and Discussion: Ancillary data



ECa

0	**Topsoil**
0.75	**EM38h**



Dermosols

Old Alluvium Meander Plain

Old Alluvium Back Plain

Vertosols

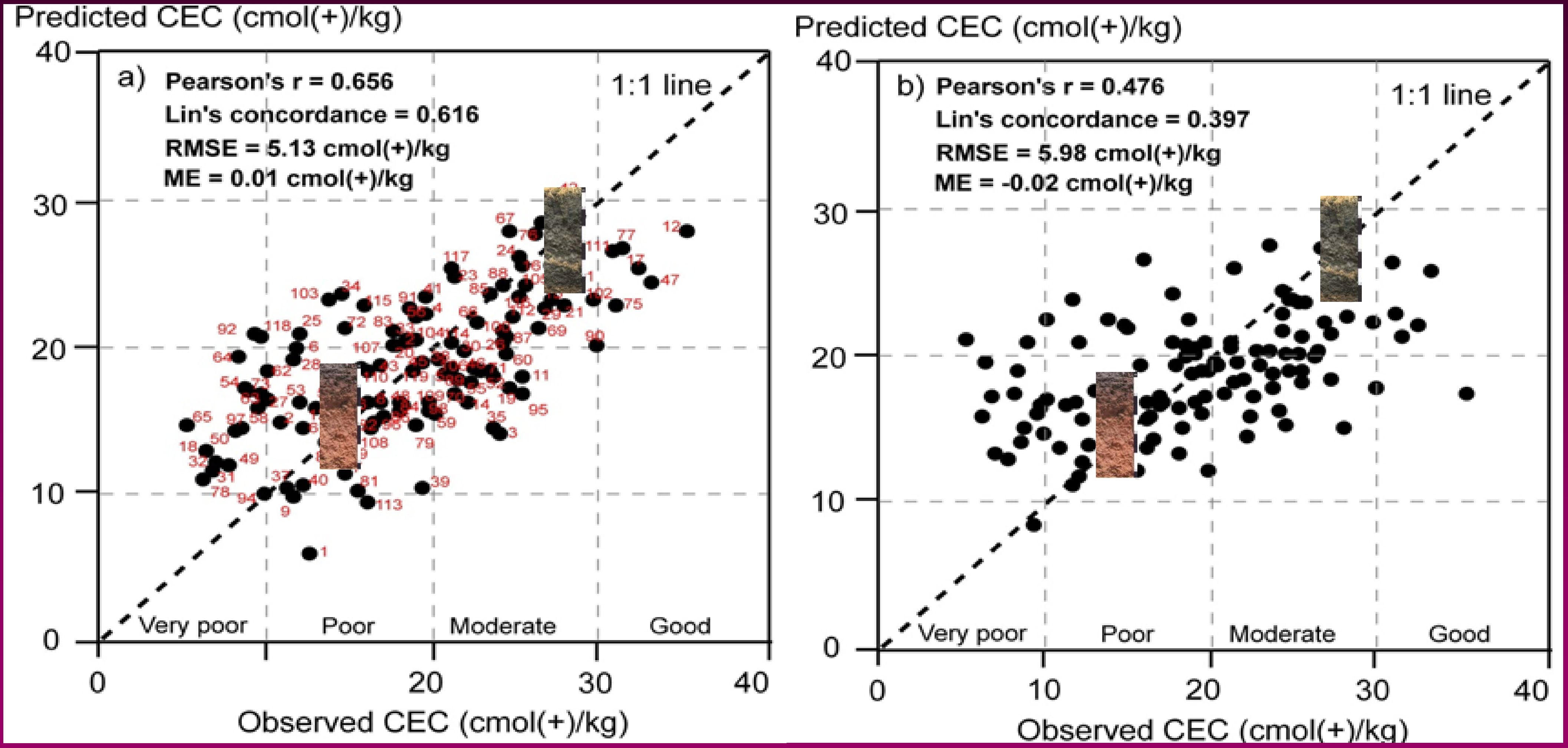
Results and Discussion

LMM models - fixed effect components

Spherical model	Estimates	Standard Error	Prob > |t|	Exponential model	Estimates	Standard Error	Prob > |t|
intercept	1.690	5.948	0.777	intercept	1.975	6.004	0.743
U	-11.434	3.531	0.002	U	-11.477	3.517	0.001
Th	3.893	0.969	<0.001	Th	3.920	0.973	<0.001
em34_10	0.285	0.047	< 0.001	em34_10	0.283	0.047	<0.001
em34_20	-0.122	0.042	0.004	em34_20	-0.124	0.042	0.003

Results and Discussion: Accuracy

Input

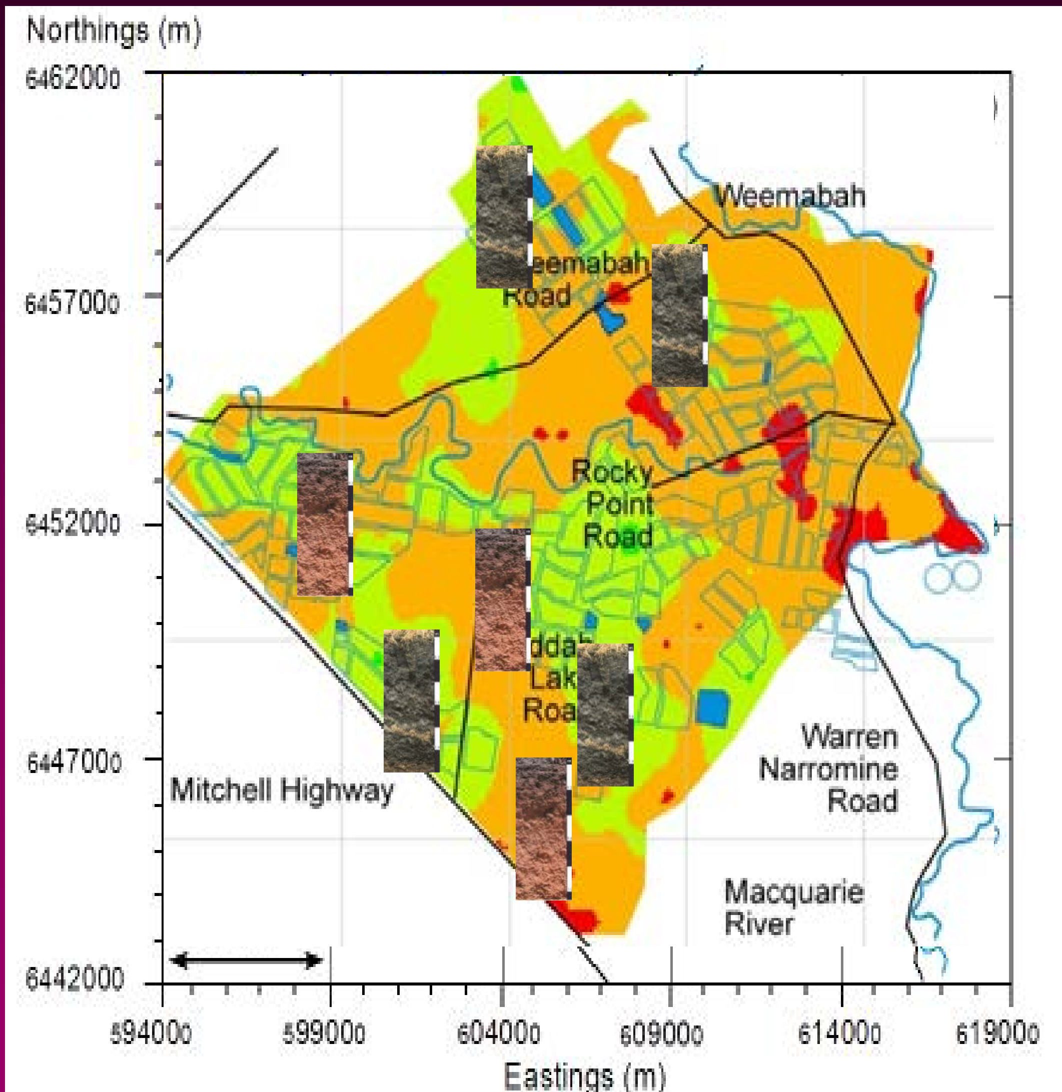


Results and Discussion: Visualisation

What do all these numbers mean?

Jasper Johns *0 - 9 1961* Oil paint on canvas

Results and Discussion: Prediction



Cation Exchange Capacity

CEC

(cmol(+)/kg)

- < 10
- < 20
- < 30
- >= 30

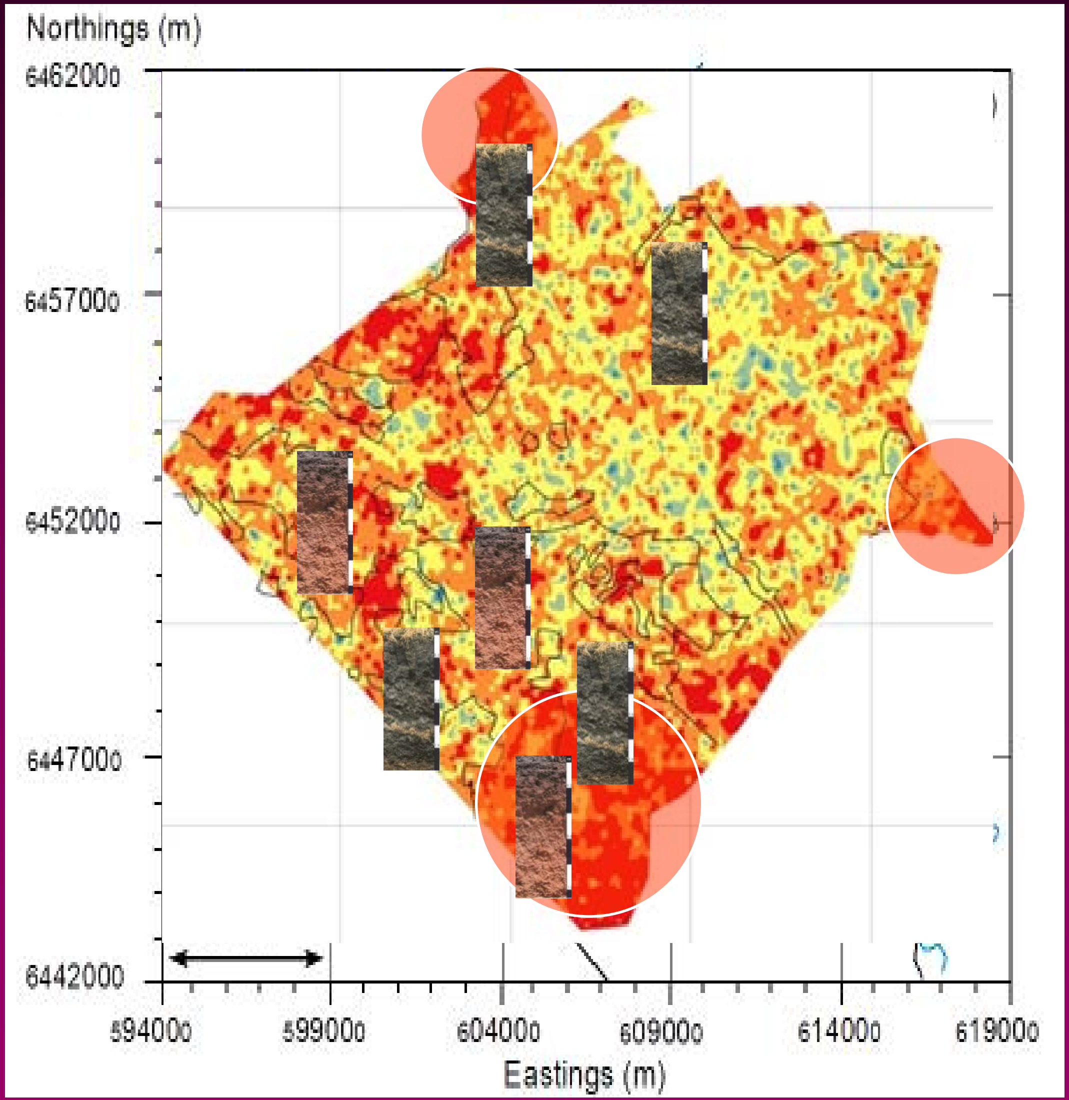
Dermosols

Old Alluvium Meander Plain

Old Alluvium Back Plain

Vertosols

Results and Discussion: Error



Model

Influenced by;
i) edge effects, and
ii) Pedoderm boundaries

SD

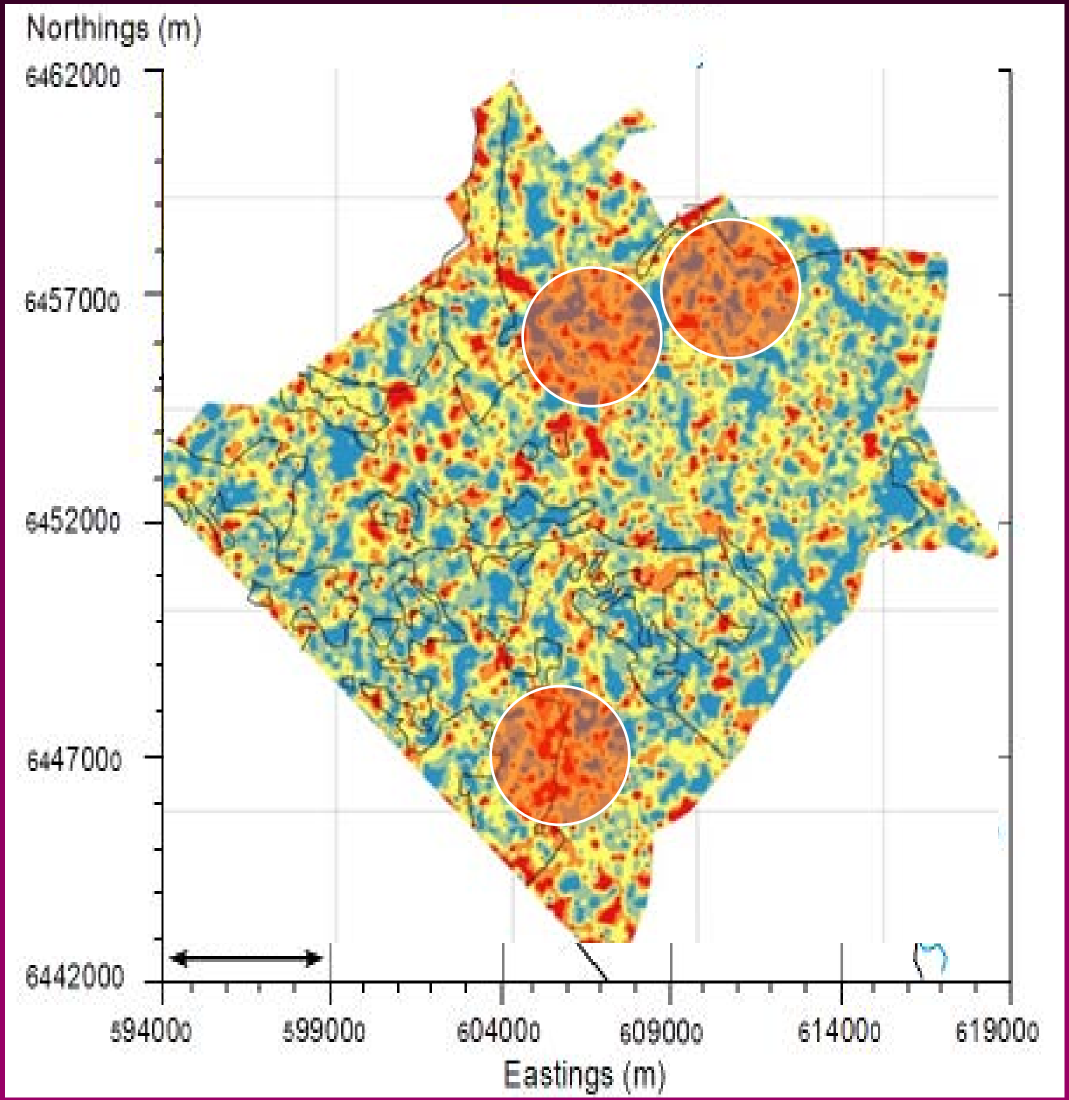
Dermosols

Old Alluvium Meander Plain

Old Alluvium Back Plain

Vertosols

Results and Discussion: Error



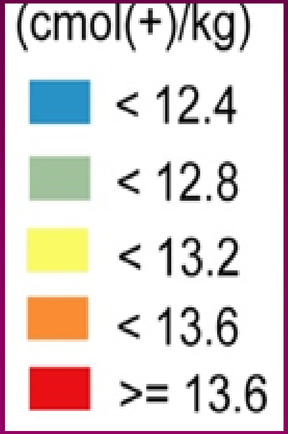
Input

Influenced by;

i) Pedoderm boundaries,

ii) Land-use management effect

SD

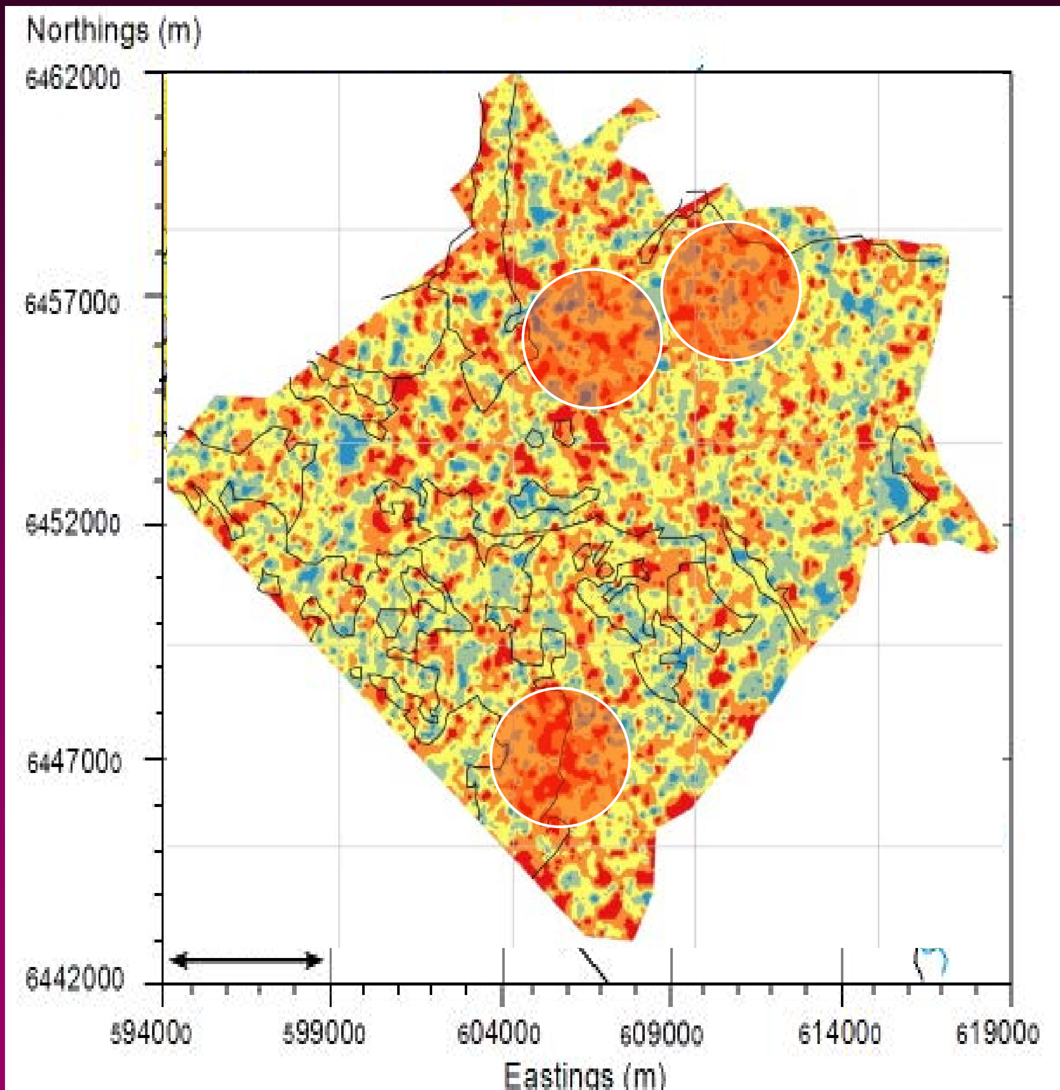


>

Input > Model

…because we estimated ancillary data onto calibration points

Results and Discussion: Error



Combined

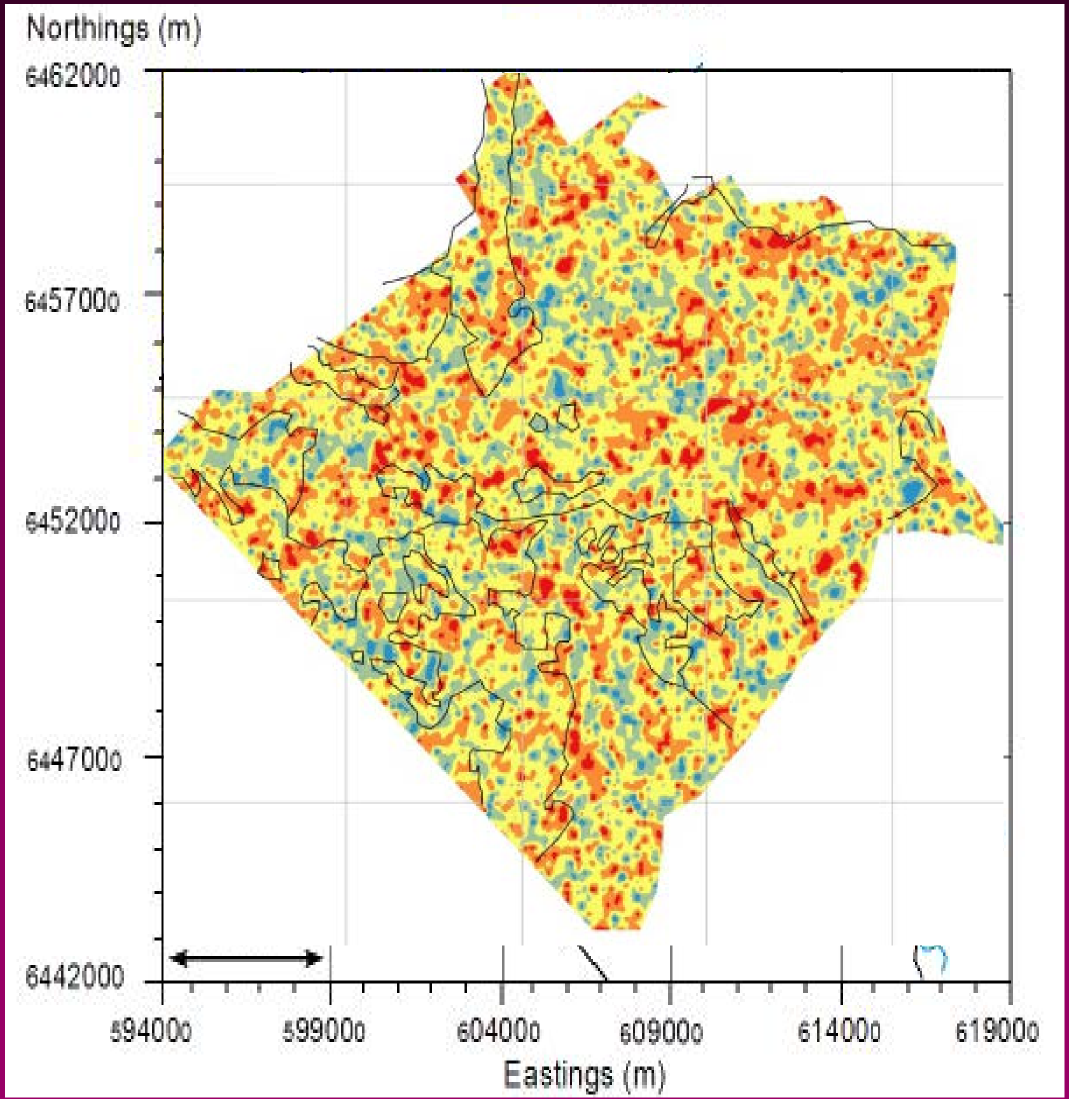
Influenced by;

i) **Pedoderm boundaries, and**

ii) **Ancillary data (???)**

SD

Results and Discussion: Error



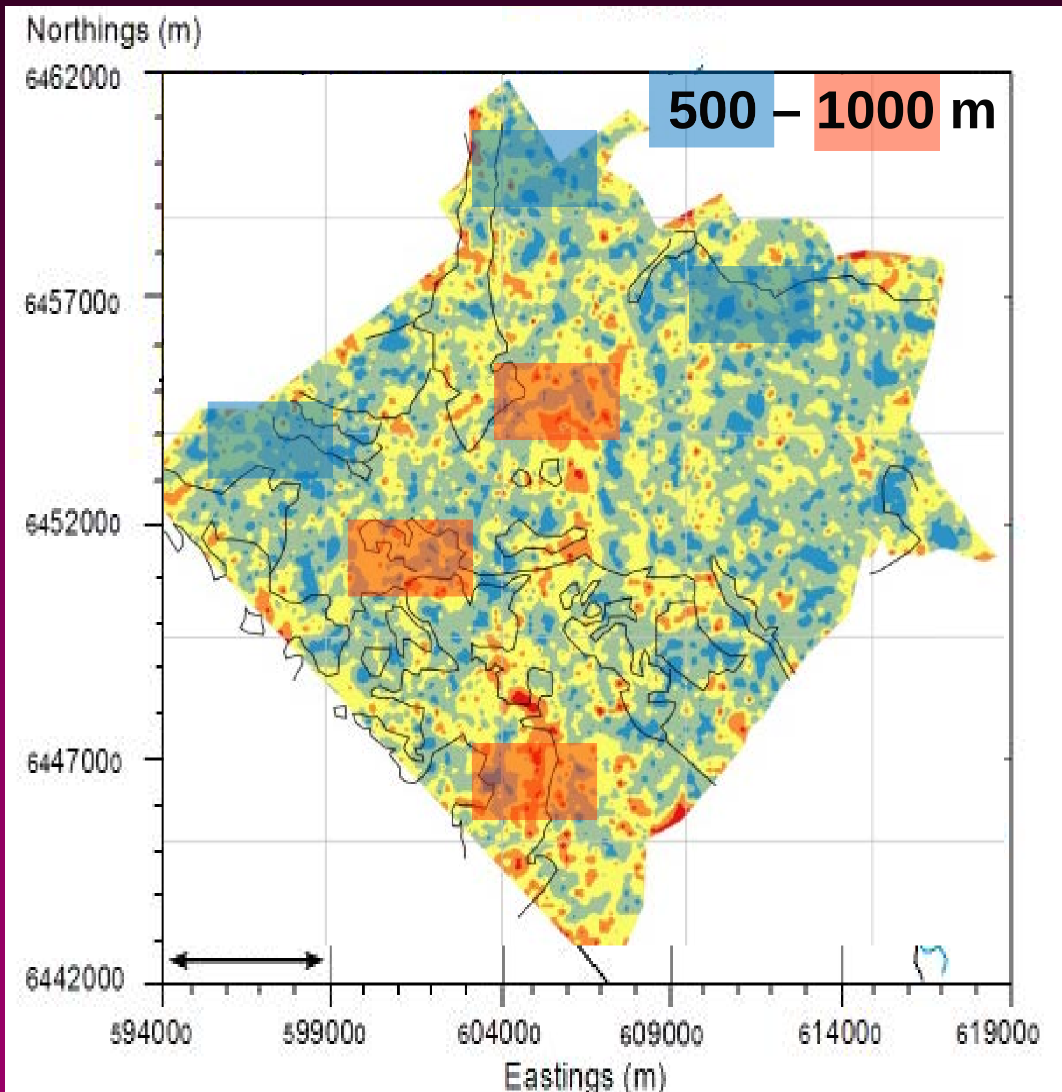
γ-ray

Influenced by;

i) Not really sure but if there is a psychologist in the room?

SD

Results and Discussion: Error



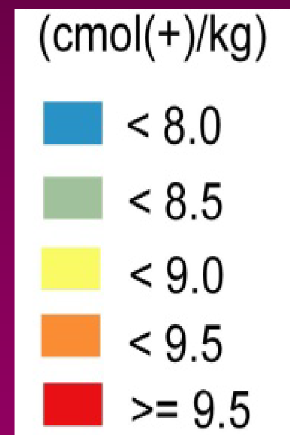
EM

Influenced by;

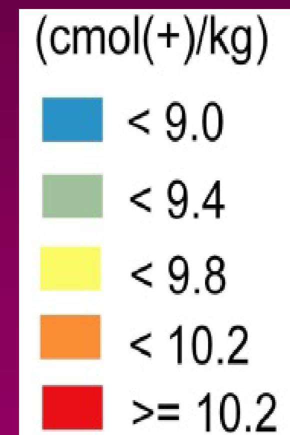
i) Dryland and irrigated sampling density

ii) Pedoderm boundaries

SD



<



EM < γ-ray

…because smaller nugget variance

Conclusions

Main

Combined error ~12.93 cmol(+)/kg is larger than observed CEC (6.8 cmol(+)/kg)

To reduce model error

applying some pre-processing techniques to improve the data quality or to look use other available ancillary data

To reduce input error

use smaller sampling interval and in particular near the edges of the survey extent and also at Pedoderm boundaries.

Jasper Johns
0 through 9 1961 Oil paint on canvas
Tate - Presented by the Friends of the Tate Gallery 1961

An error budget for mapping field-scale soil salinity at various depths using different sources of ancillary data

Huang, J., Barrett-Lennard, E., Kilminster, T.,
Sinott, A., Triantafilis, J.

Jingyi Huang
School of Biological, Earth and Environmental Sciences
Univ. of New South Wales
Kensington NSW, 2052
Australia

Edward G. Barrett-Lennard
School of Plant Biology
The Univ. of Western Australia
Crawley WA, 6009
Australia

and
Dep. of Agric. and Food Western Australia
Kensington WA, 6151
Australia

Tanya Kilminster
Dep. of Agric. and Food Western Australia
Merredin WA, 6415
Australia

Aidan Sinnott
Precision Agronomics Australia
9 Currong St.
PO Box 2418
Esperance WA, 6450
Australia

John Triantafilis*
School of Biological, Earth and Environmental Sciences
Univ. of New South Wales
Kensington NSW, 2052
Australia

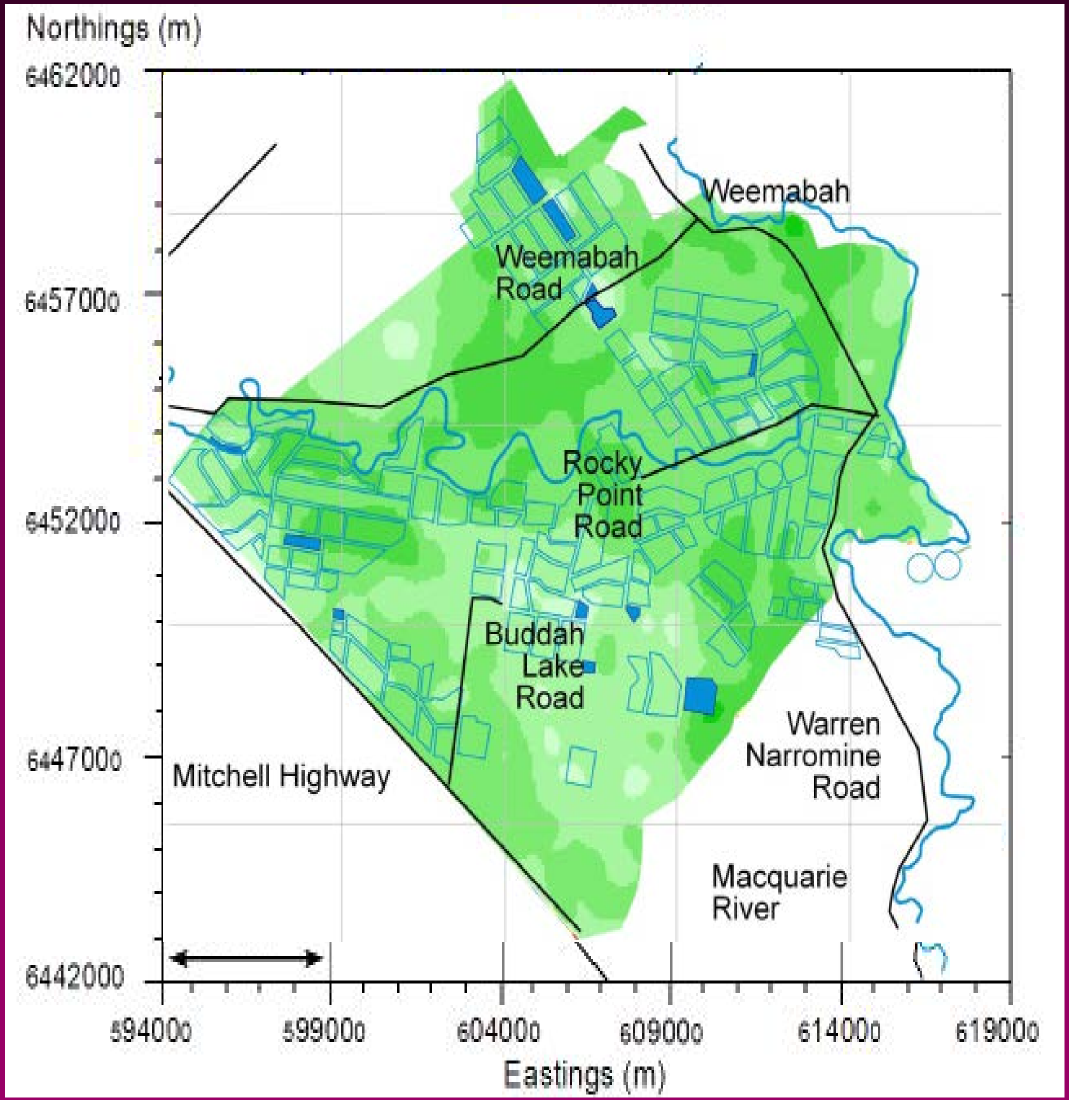
Pedology

An Error Budget for Mapping Field-Scale Soil Salinity at Various Depths using Different Sources of Ancillary Data

To manage soil salinity, farmers need to map its variation, often quantified as the electrical conductivity of a saturated soil-paste extract (EC_e, dS m^{-1}). However, EC_e determination is time-consuming and expensive. Previous studies have evaluated the use of digital elevation models (DEMs, i.e., elevation), airborne γ-ray (γ-ray) spectrometry (i.e., K, U, and Th) and electromagnetic (EM, i.e., EM38 and EM34) data to map EC_e at the district scale. Herein we use similar ancillary data set and empirical best linear unbiased prediction (E-BLUP) to make maps of EC_e at different depth intervals (0–0.25, 0.25–0.50, and 0.50–0.75 m) at the field scale. The ancillary data was collected using a ground-based mobile sensing system which included; a GPS which provided spatial coordinates (Easting, Northing), a RS700 (γ-ray) mobile spectrometer, and a DUALEM-1. An error budget procedure was conducted to quantify the model, input, and individual covariate errors of EC_e. Results show that while none of the γ-ray data were significant, scaled Easting, elevation, and 1-m horizontal coplanar (1mHcon) were optimal for mapping EC_e at 0 to 0.25 m, while 1mHcon was optimal at 0.25 to 0.50 m and 0.50 to 0.75 m. Among all the individual covariate errors for mapping 0- to 0.25-m EC_e, elevation (0.40 dS m^{-1}) was smallest, followed by 1mHcon (2.23 dS m^{-1}). To reduce error, additional soil samples are necessary to prevent the edge effect of the kriging process. Additionally, inversion of EM data could be used to improve EC_e mapping considering the relatively large model error associated with EM data in the subsoil of inverted salinity profiles.

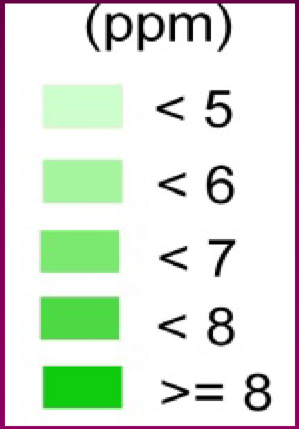
SSSAJ
SOIL SCIENCE SOCIETY OF AMERICA JOURNAL
79, 1717-1728

Results and Discussion: Ancillary data



Gamma-ray spectrometry

0	**Topsoil**
0.35	**Thorium**



Results and Discussion

LMM models - variogram and goodness fit

Variogram	Spherical	Exponential
σ^2 (partial sill)	6.108	6.847
range	1.1	0.4
nugget	21.88	21.17
Log-likelihood	-346.3	-346.7

Model		Spherical	Exponential
Pearson' r		0.656	0.653
Lin's	Estimate	0.616	0.612
SSPE	Mean	1.007	1.007
	Median	0.617	0.588
ME (cmol(+)/kg)		0.011	0.011
RMSE (cmol(+)/kg)		5.129	5.152

Introduction

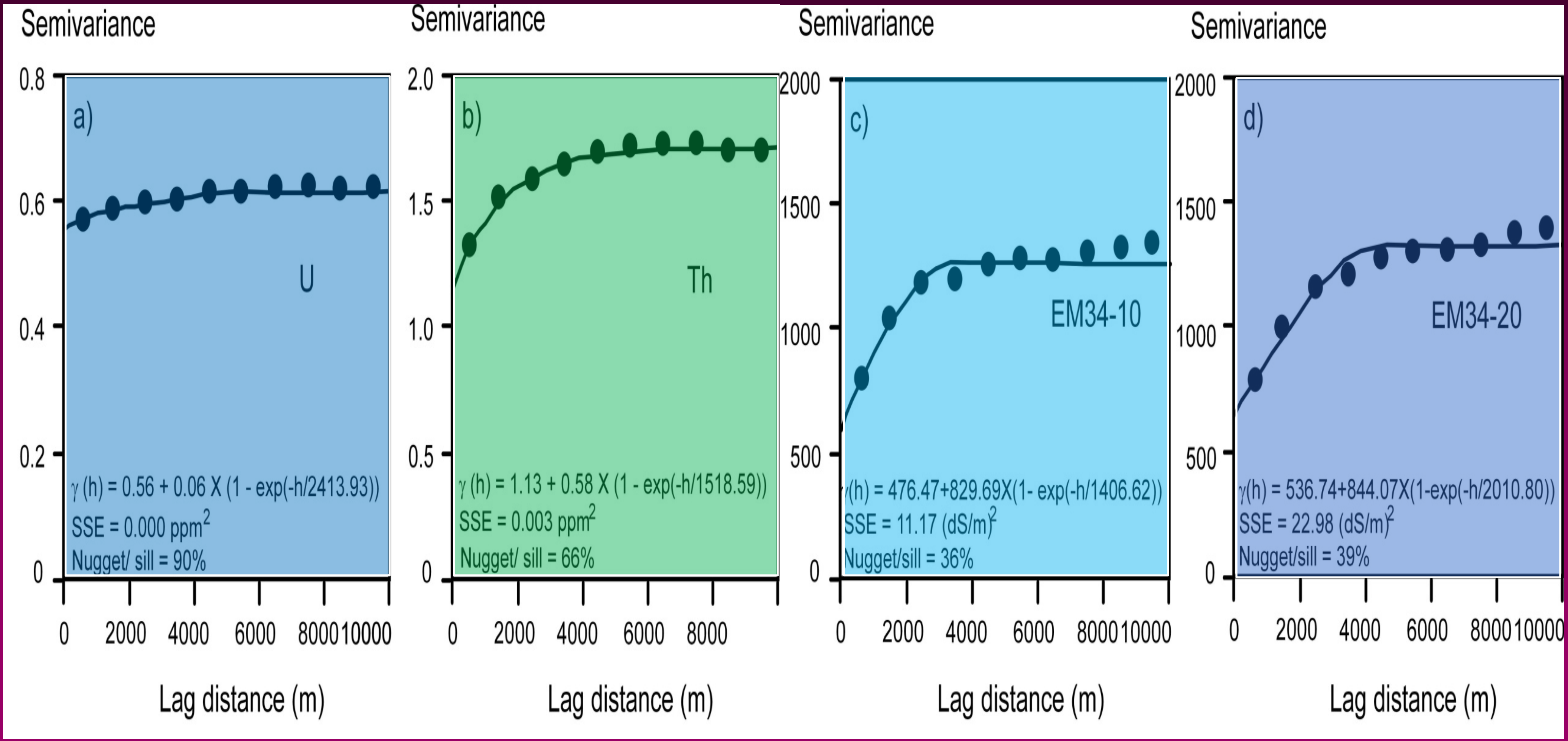
Murray Darling Basin

Owing to the semi-arid climate, large areas extensively developed for irrigated agricultural production.

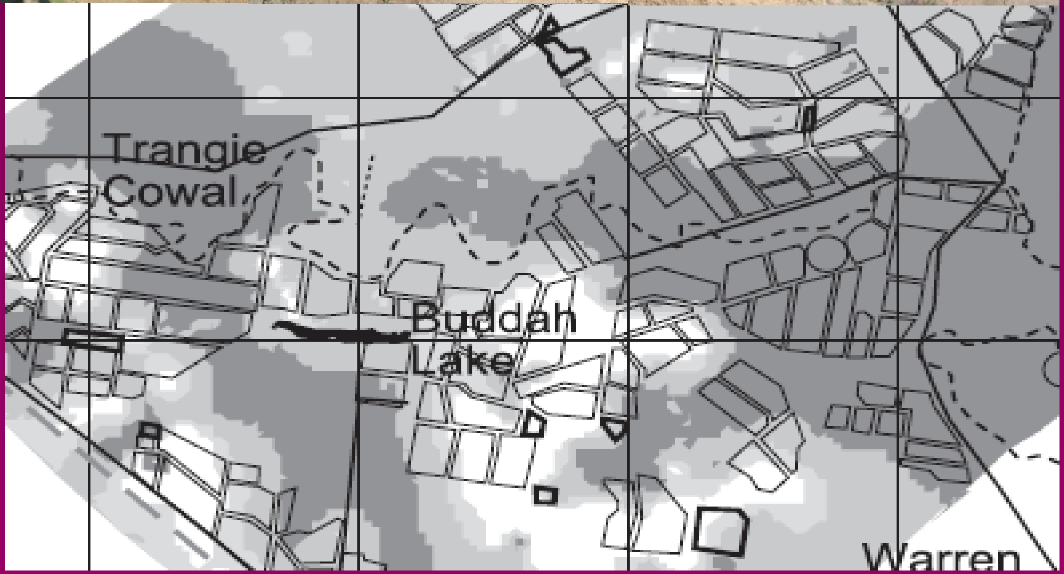
Whilst irrigation to Vertosols has brought prosperity, there have been some isolated environmental impacts.

Results and Discussion

LMM models - variogram and goodness fit



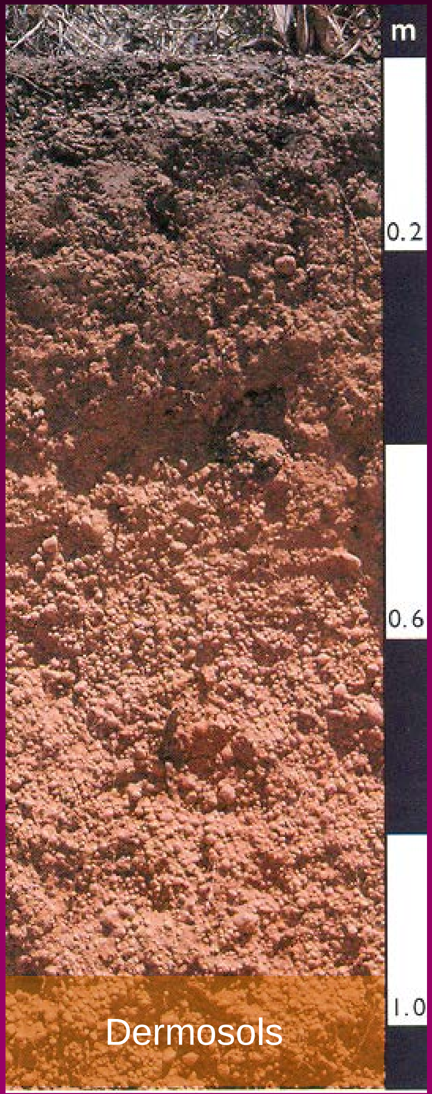
Introduction



Environmental impacts

One of these has been the creation of shallow saline water tables (e.g. Buchanan and Triantafilis, 2009).

One of the drivers has been susceptibility of landscape to deep drainage (Woodforth et al., 2012) via prior stream channels (Dermosols).



Gamma-ray spectrometry

Application

Depth (m)

Remote (air-borne)

Topsoil

0

0.4

Airborne

K

U

Th

TC

Mapping
clay content,
CEC,
mineralogy

EM instruments

Application

Root zone

Sub-soil

Mapping
clay content,
salinity, CEC
and moisture
status

Operating Frequency:
14kHz

Depth (m)

h v

0

0.75

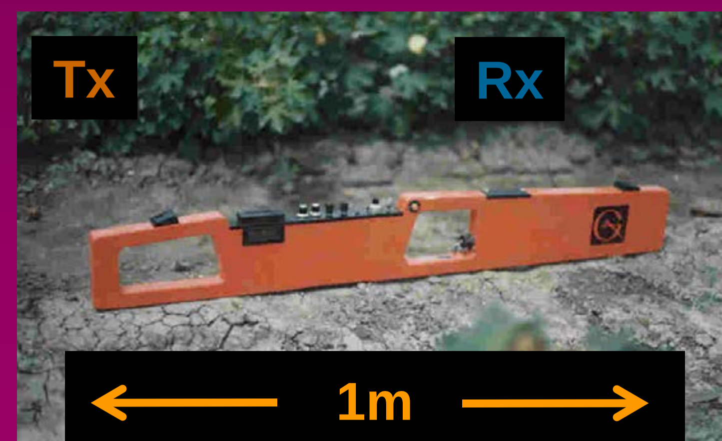
1.5

Proximal

Geonics EM38

EM38h

EM38v



EM instruments

Application

Depth (m)

h

Proximal

Geonics EM34

0

Vadose zone

Shallow groundwater tables

7

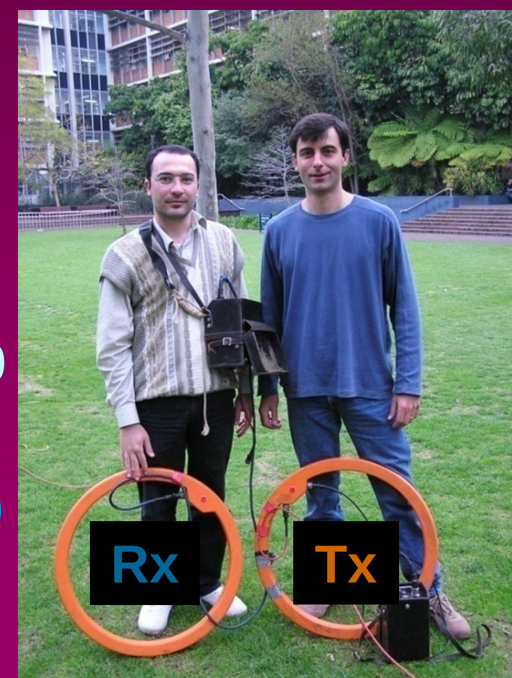
EM34-10

15

EM34-20

30

EM34-40



Operating Frequency:
6.4, 1.6 and 0.4 kHz